Source Term Balance for Finite Depth Wind Waves

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LONG-TERM GOAL

The long-term goal is to obtain closure of the energy balance equation for wind wave evolution in finite depth water by means of direct measurement of the main source terms. These source terms represent the basic physical processes required to develop reliable finite depth wave prediction models.

SCIENTIFIC OBJECTIVES

The objectives are to establish a description of the basic sources/sinks of energy responsible for shallow water wind-wave evolution, namely dissipation due to both wave breaking and bottom friction, and wind input. Spectral distribution of "white-capping" dissipation has not previously been obtained either experimentally or theoretically, and currently, speculative approaches are used to represent this term in wave models. The natural phenomena determining this term are random, non-linear and related to extreme wave conditions and hence are difficult to evaluate in the field. The other two terms have been the subjects of intensive research during the last three decades, although detailed field observations are rare. However, while there is a qualitative understanding of their behaviour, no established quantitative description is available.

APPROACH

An integrated set of measurements in the atmospheric and sub-surface boundary layers as well as on the surface itself has been carried out at the Lake George field experimental site in September, 1997

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14. ABSTRACT
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15. SUBJECT TERMS

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through August, 2000, whenever meteorological forecasts were appropriate. In August - September, 1999, the end of the Southern Hemisphere winter and a time of regular cross-lake winds, an intensive observation period was conducted. The previous measurements were supplemented by fine-scale measurements of wave-induced air pressure, sub-surface turbulence and bottom boundary layer velocity profiles. This latter experiment, conducted collaboratively with two U.S. groups from the University of Miami and the Scripps Institute of Oceanography, was titled AUSWEX (AUstralian Shallow Water EXperiment).

AUSWEX was followed by two sets of laboratory experiments in the School of Civil Engineering at the Australian Defence Force Academy (ADFA) to improve estimates of the wave energy dissipation due to interaction with the lake bed. The intensity of the field observations was scaled down after AUSWEX, although some super-shallow environment records were obtained. The Lake George field site was closed down and dismantled in September, 2000, thus concluding the three year long period of active observations started in September, 1997. Extensive analysis of the accumulated data followed.

The spectral wind input function was chosen as the first source term to be thoroughly examined based on the Lake George field data. The wind input spectrum is directly measured using a wave follower and while it is the least speculative source term, it requires complex data processing technology. To develop this technology, detailed analysis of the data had to be supplemented with laboratory tests at the Rosenstiel School of Marine and Atmospheric Science (RSMAS) in Miami together with theoretical considerations. Once a detailed knowledge of the wind input function has been developed, the other source terms, as well as total energy balance, will be thoroughly investigated in the spectral sense.

Full details of the Lake George field experimental facility and instrumentation can be found in the 1999 Progress Report and this information is not repeated here.

WORK COMPLETED

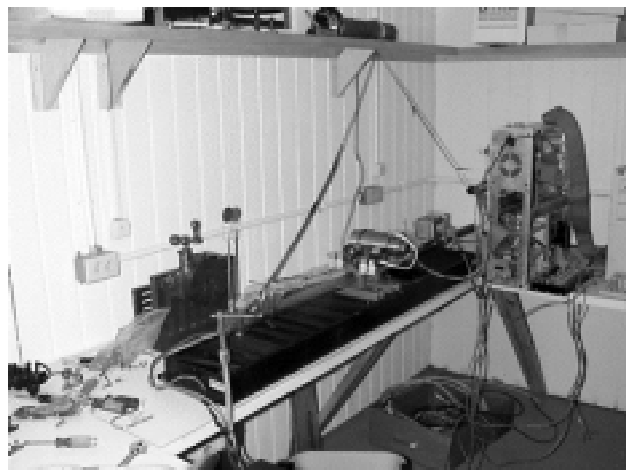
Data from the Lake George site were obtained for three years, including the intensive AUSWEX period. A database, containing hundreds of hours of wave, wind, air turbulence, sub-surface currents and turbulence, under-water sound, humidity, air and water temperatures and other records, as well as photographic images of the surface, was prepared, documented and is available on seven CDs. About 90 hours of relevant video and hydrophone sound records, with synchronising time code, are available on two sets of 30 Super-VHS video tapes.

The joint AUSWEX experiment was carried out from 14 August to 18 September, 1999. The data acquired comprise numerous synchronised records by the wave array, anemometer masts, sonic anemometer, three acoustic doppler velocimeters (ADV) located at different levels in the water column, video camera, hydrophone, humidity and temperature probes, as well as by the Dopbeam, which was traversed to different depths, and by the wave follower. These data comprise four CDs and about 45 hours of video and hydrophone sound records.

A number of laboratory tests were conducted to clarify fine details of the physical processes and the complex behaviour of measurement devices. An extensive data analysis has been carried out to obtain

the wind input spectral function, to study wave breaking probability, the total wave energy dissipation, to estimate wave-bottom interaction and to verify the total energy balance of the wave field.

The two photographs below demonstrate both the field and laboratory stages of the Lake George experiment. The photo on the left shows the field site prior to the major AUSWEX phase. The platform, accessible by the elevated walkway, was constructed outside the surf zone to carry out the measurements. As seen in the picture, the platform includes an accommodation module to house researchers, computers and recording equipment, and also includes the measurement bridge and anemometer mast. Once the field part of the Project was completed, the platform was dismantled. The second photo shows testing of the performance of the Elliott pressure probe response in the Air-Sea Interaction Salt-water Tank (ASIST) at RSMAS. The wave follower was operated in a horizontal position to simulate pressure oscillations caused only by the acceleration of the probe.



As a result of the Lake George Project, several papers have been published and presented at international conferences. During the last year, two talks were delivered at the WISE-8 meeting in Ontario, Canada and papers were published in the Journal of Physical Oceanography (Banner, Babanin, and Young, 2000) and in the Journal of Geophysical Research (Babanin, Young and Banner, 2001). Two more papers are being prepared for the Journal of Atmospheric and Oceanic Technology and the Journal of Fluid Mechanics by Donelan, Babanin, Young and Banner.

RESULTS

The total energy balance, based on synchronous field measurements of the total wind input, the total water column dissipation and the total bottom dissipation, were verified last year. Major attention has now been concentrated on the detailed study of the spectral distribution of wind input and the dependence of the input on the properties of the wave field and the boundary layer air flow. The wind input is the most directly measurable source function and has served as a starting point for a thorough study of the wind wave spectral balance.

Unlike the other source terms, the wind input spectral function can be directly determined from the pressure - surface slope correlation. Such measurements require use of a high precision wave follower system. The wave follower used at Lake George (designed by Mark Donelan and his RSMAS group)

could follow the wavy surface with high coherence to frequencies of 5 Hz and higher. However, the pressure signal needs multiple and complex corrections, both in amplitude and phase, to account for the effects of the pressure transducer response, leakage from the outside pressure to the backup volume, the stage displacement and the acceleration of the air in the connecting tubes. Failure to properly make any of these corrections results in contamination of the pressure signal, parasitic surface-pressure correlations and crucially affects the resulting wind input function.

It proved particularly important to correct for air column acceleration. To properly determine this influence, special tests were conducted at the ASIST tank at RSMAS, with the same wave follower and Elliott pressure probes used at Lake George. These tests showed (see Fig.1, left panels) that the pressure response is not simply the second derivative of the acceleration, as had been previously assumed in similar studies, but has a phase dependence which will induce very significant spurious correlations at higher frequencies, unless carefully removed in Fourier space.

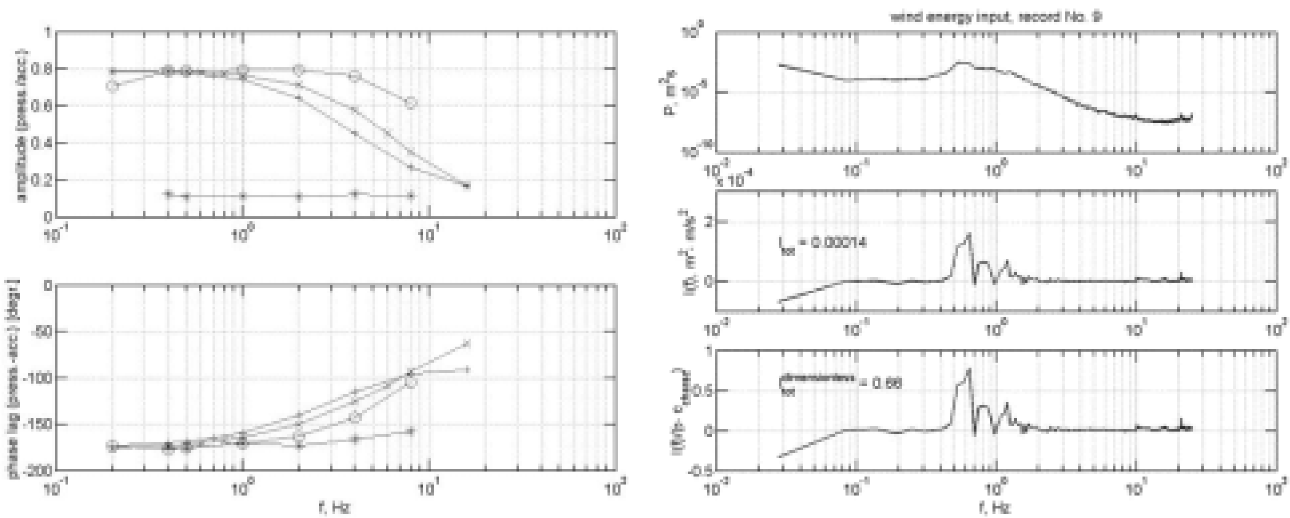


Fig.1. Left panels: Frequency dependence of pressure induced by acceleration of the air column in the tubes connecting the pressure probe and pressure transducer. The dependence is strong both for the relative pressure amplitude and the phase shift between the pressure and the acceleration. The phase shift is negative which means that the pressure lags the acceleration. Right panels: The water surface elevation power spectrum (P) of the surface elevation (top); corresponding measured dimensional (middle) and non-dimensional (bottom) wind input spectral function. The wind input functions peak at the same frequencies as the power spectrum. Values of the total wind input are also shown.

The pressure and surface elevation records were corrected for instrument response and the input source term was determined. Fig.1 (right panels) shows one of the measured wave power spectra and the corresponding wind input spectral distribution (dimensional and non-dimensional). All the functions peak at approximately the same frequency, which means that for the strongly forced wave conditions at Lake George, most of the energy input takes place through the dominant waves.

A set of wind input source terms, corresponding to varying wind-wave conditions, was obtained, which allowed determination of the input function of the form:

$$I(f) = \frac{\rho_a}{\rho_w} g\gamma(f) fP(f),$$

where the spectral growth increment function $\gamma(f) = a(\frac{U_{\lambda(f)/2}}{c} - 1)^2$.

These formulas can be used directly to calculate the wind input based on the wave spectrum and the local mean wind information, which is usually available.

The coefficient *a,* which equals *0.14* for the Lake George data set, appears not to be a universal constant. For example, the laboratory results of Donelan (1999) yield *a = 0.28,* twice as large as the present data set. This variability, which now appears to be related to a dependence of the wind input on the wave breaking activity, has been investigated in detail and is described in report ONR N00014-00-1-0012 (CDYoun02).

IMPACT/APPLICATION

Results of the field research and parameterization of the source terms will have potential impact in a number of areas.

1).**Wind Wave Dynamics**. Direct, simultaneous, in situ field measurements of the major source terms, together with detailed knowledge of the spectral evolution, have not previously been attempted. The results have the potential to provide considerable insight for improving present understanding of wind wave evolution in finite depth water. Spectral wind input and dissipation functions, applicable to wave modeling, will be determined.

2).**Wave Modeling**. Source terms presently used in finite depth wave prediction models are largely extrapolated from deep water experience. Direct measurement of the source terms in finite water depth situations will provide a more appropriate representation for the physical processes in such models. As a result, an enhanced ability to predict near-shore wave conditions should result.

TRANSITIONS

Two groups have used the Lake George facility collaboratively during AUSWEX and are currently using the Lake George data. Another two groups intend to use results of the experiment for verification of their theoretical models.

Mark Donelan from the University of Miami installed and successfully operated his wave follower during AUSWEX, is participating in the data processing and is using the combined data set for analysis of the wind input source function.

Kendall Melville from the Scripps Institute of Oceanography provided his Dopbeam acoustic water turbulence sensing system during AUSWEX and is part of the data processing and investigation team for studies of sub-surface turbulence and total dissipation of wave energy.

Vladimir Makin from the Royal Dutch Meteorological Institute (KNMI), De Bilt, The Netherlands plans to provide theoretical interpretation by means of his wind-wave coupling model based on using data of observed distributions of mean and wave-induced stresses.

Gerbrant van Vledder from Alkyon Hydraulic Consultancy & Research, The Netherlands, is planning to use the Lake George data set for extensive tests of numerical wave models.

RELATED PROJECTS

This Project is coordinated with the DRI experiments conducted at Duck, North Carolina, and Ian Young, head of this Project, took part in the field experiment at Duck. As the Lake George experimental site provided good control over the environmental parameters, it is hoped that our experiment may well fill some of the gaps in the larger scale, open ocean DRI measurements. A related ONR-funded Project (N00014-00-1-0012) is investigating detailed modeling aspects resulting from the source term determined in this study.

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